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CONVAIR DIVISION OF GENERAL DYNAMICS CORPORATION

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SM-65 - D & E

LIQUID OXGEN SYSTEM ANALYSIS

BASED ON

ENVIRONMENTAL CONDITIONS

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INTRODUCTION

An analysis of the capabilities of the liquid oxygen system has been made based on the data presented in Report ZL-7-068, "Climatological Data Survey for Omaha, Nebraska; Spokane, Washington; Cheyenne, Wyoming and Topeka, Kansas." The results are presented in this report. ( )

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1. SCOPE

This report contains an analysis of the capabilities of the liquid oxygen system based on the data presented in Report No. ZL-7-068, "Climatological Data Survey for Omaha, Nebraska; Spokane, Washington; Cheyenne, Wyoming and Topeka, Kansas." This study has been limited to the months of July and August at Omaha since this period and location impose the most severe conditions on the liquid oxygen system.

2. BASIC ASSUMPTIONS

The following assumptions were used as a basis for the application of the climatological data to arrive at the system capabilities.

A liquid oxygen storage tank of 28,000 gallon capacity will be standard at the sites under consideration.

The liquid oxygen topping system for "D" series sites and "E" series sites will have a maximum flow rate capability of 200 GPM, except 65-1.

The climatological data in Report No. ZL-7-068 indicates that the months of July and August at Omaha, Nebraska, will impose the most severe conditions on the liquid oxygen system with respect to temperature, humidity, wind velocity, precipitation and combinations thereof. Further, Omaha weather conditions are fairly typical of that to be expected throughout the central portion of the Great Plains. Therefore, conclusions drawn based on this data will be applicable for other sites located in this area and for sites in other geographical areas equipment and/or probabilities will be more than adequate since less severe conditions prevail there.

In determining all probabilities in this report a standard operational cycle consisting of the following steps was used:

Load propellants
Hold
Unload propellants
Reload
Launch

In each instance the hold time referred to is that hold time which can be met considering the above sequence of operations.

3. CONCLUSIONS

The topping flow rate capability of 200 GPM for the sites will be more than adequate for anticipated environmental conditions.

Missile environmental protection is not considered practical for operational sites and based on the data herein it is not deemed to be a requirement.

All probabilities, except the yearly curve, are based on climatological data for July and August at Omaha, Nebraska. As is borne out by the curves, this time and location impose the mose severe requirements on the liquid oxygen system. Therefore, conclusions drawn and recommendations made will be valid not only for this particular site, but for all others as well.

Based on a liquid oxygen storage capacity of 28,000 gallons the operational requirement to load propellants, hold one hour, unload, reload and launch cannot be met by the system one hour in every eighty. If however, the required hold time were decreased to 40 minutes, the possibility of a system functional failure (i.e., inability to meet the required hold) is decreased to only one hour in 450. In each case the probability is based on the ability of the liquid oxygen storage capacity to sustain the required topping flow rate for the hold time indicated. To attain a similar probability (1 in 450) for a one hour hold would require approximately 1500 gallons of additional liquid oxygen storage capacity. The economic feasibility of this or any increase in liquid oxygen storage capacity must be weighed against the desired successful launch probability.

The heat flux due to ice buildup because of rain impingement on the missile liquid oxygen tank becomes independent of wind velocity and other environmental conditions when the ice buildup exceeds 3/8" in thickness. The boiloff rate due to this ice buildup will permit a hold of approximately 50 minutes. This hold time coupled with the pro-

bability of a significant rainfall occurring does not appear to be critical, therefore the effects of rainfall are not given any further consideration.

4. RECOMMENDATIONS

Based on the information contained herein it is recommended that:

Environmental protection for the missile be deleted as a requirement.

Liquid oxygen topping flow rates of 200 GPM at "D" and "E" sites be considered adequate and no further design effort be expended to increase system capabilities beyond these rates.

5. DISCUSSION

5.1 Use of Curves

5.1.1 Figures 1 - 8 are all cumulative "more than" distributions of various climatological items. They are based upon Weather Bureau Monthly Summaries of the hourly readings for each particular item. These particular curves represent data for the period of interest, July and August, extracted from references 2 and 3 and as such are based on approximately 4500 hourly readings taken during three typical years.

These curves give a direct reading of the percent of the time which the graphed factor may be expected to exceed a given value. With reference to figure 1 for example, it can be seen that during July and August wind velocities in excess of 15 miles per hour can be expected approximately 16% of the time and in excess of 25 miles per hour only ½ of 1% of the time. Conversely wind velocities of 15 miles per hour or less can be expected 84% of the time (100-16).

5.1.2 Figure 9 is based on information contained in reference 4 as applied to the "D" and "E" series systems. It provides a correlation between various combinations of environmental conditions and the anticipated boiloff rates and allowable hold times for these conditions.

For example, with a relative humidity of 80%, temperature of 80°F and a wind velocity of 40 mph a topping rate of 118 GPM will be required. This topping rate could be maintained for 25 minutes based on the 28,000 gallon storage tank.

5.1.3 Figure 10 provides an approximate System Functional Failure Probability vs. Hold Time. A family of four curves has been graphed and indicate failure probabilities for the following time intervals:

January - December
July - August
July - August 6:00 AM - 6:00 PM
July - August 6:00 PM - 6:00 AM

These groupings were taken to determine what variations in probabilities would be encountered due to seasonal as well as daytime vs. nighttime variations in the environmental conditions. As can be seen, all four curves fall within a relatively narrow envelope. This would indicate that probabilities based on data cumulated over a one year period may be used with reasonable accuracy during even the more critical summer months in so far as the liquid oxygen system is concerned. For hold times in the 30 to 50 minute bracket the evening hours during July and August are slightly more critical than other times. This is due primarily to the higher humidity generally encountered during these hours.

To understand what factors were considered in arriving at these curves, let us briefly examine the development of them. Essentially the curve is based on the data presented in figure 9, a 28,000 gallon liquid oxygen tank and the anticipated boiloff rates due to various combinations of relative humidity, temperature and wind velocity. Effects of rainfall will be discussed in a separate section.

Hold times in ten minute increments were considered sufficient to establish the points on the curve. For each hold time established, figure 9 can be utilized to determine corresponding combinations of environmental conditions which would result in that hold time. For example:

Hold time: 30 min.

Corresponding anticipated boiloff
and/or topping rate: 104 GPM

Entering the upper right quadrant curves vertically at this point any desired wind velocity may be chosen for study. Proceeding horizontally left from the wind velocity chosen, a series of temperatures can then be read in the upper left quadrant. Corresponding to each temperature chosen will be a relative humidity value. The various combinations of environmental conditions thus obtained for each hold time considered were tabulated. Probabilities of the occurrence of each combination were then computed based on figures 1-8. For each hold time, the worst probability (that is the one indicating the most frequent chance for system failure) was chosen to be graphed since it represented the critical condition and that which was most likely to be encountered. The tabulation below shows the governing environmental factors thus determined for each hold time interval.

	Environmental Conditions			Approximate
Hold Time	Wind Velocity	Temperature	Relative Humidity	Topping Rate Required
		JULY & AUGUST		
10 Min.	60 MPH	100°F	69%	200 GPM
20	50	80	72	140
30	40	70	65	100
40	30	70	72	80
50	20	90	63	70
60	20	70	72	60
		6:00 AM-6:00 PM JULY & AUGUST		
10	60	100	69	200
20	50	80	72	140
30	50	50	15	100
40	30	70	72	80
50	30	50	15	70
60	20	70	72	60

Hold Time	Environmental Conditions: Wind Velocity	Temperature	Relative Humidity	Approximate Topping Rate Required
	6:00 PM-6:00 AM JULY & AUGUST			
10 Min.	60 MPH	100°F	69%	200 GPM
20	60	60	80	140
30	40	70	65	100
40	30	70	72	80
50	30	50	15	70
60	30	45	15	60
	JANUARY - DECEMBER			
10	60	100	69	200
20	60	60	80	140
30	50	50	15	100
40	30	70	72	80
50	20	80	98	70
60	20	70	72	60

The basic determining factor in arriving at the probabilities is the liquid oxygen storage capacity f 28,000 gallons. All probabilities are based on combinations of environmental conditions which result in a given liquid oxygen topping flow rate. This flow rate in turn can be sustained by the available stored fluid only for the hold time shown. As the hold time is increased, the required topping flow rate decreases, but the probability that environmental conditions will be such as to demand greater flow rates increases at a very rapid rate. That is the mild conditions which permit lower flow rates and allow the extended hold are much more often exceeded resulting in inability to meet the operational requirement.

5.2 Effects of Rainfall

Only fragmentary data is available on the effect of rainfall on liquid oxygen boiloff rates. In reference 4 effects of rainfall in conjunction with wind are graphed, however the rate of rainfall used in arriving at the data is not mentioned. One important fact was that the heat flux rate becomes independent of wind velocity and other environmental conditions when the ice buildup exceeds 3/8" in thickness. This buildup normally occurs in approximately

15 minutes. Thus it appears that the affect of rainfall may be considered separately from other conditions.

Utilizing the heat flux data presented in Section V of reference 4 the hold time possible because of boiloff due to ice buildup is approximately 50 minutes. Based on tests conducted by Convair the rainfall rate utilized in the A. D. Little tests of reference 4 (comparison of ice buildup rates) was slightly in excess of .25"/hour. The probability of such a rainfall occurring is one in 165.

While the anticipated hold time because of ice buildup is important, a fact of equal significance is that during the 40 minute buildup approximately 14,000 pounds of ice will form on the missile liquid oxygen tank. The affect of this ice buildup on the missile structure is unknown.

REFERENCES

1. Convair Report No. ZL-7-068, Climatological Data Survey for Omaha, Nebraska; Spokane, Washington; Cheyenne, Wyoming and Topeka, Kansas; dated 12 February 1959.

2. Local Climatological Data, U. S. Department of Commerce, Weather Bureau, Annual Summary, Omaha, Nebraska, 1957.

3. Local Climatological Data, U. S. Department of Commerce, Weather Bureau, Monthly Summary, Omaha, Nebraska.

   a. July, 1950, 1955, 1957
   b. August, 1950, 1955, 1957

4. Arthur D. Little, Inc., Special Report #50, Atmospheric Heat Transfer to Vertical Tanks Filled with Liquid Oxygen dated 15 November 1957.

5. Elementary Statistical Methods by Neiswanger, 3rd Ed., Macmillan (New York), 1956.

CUMULATIVE "MORE THAN" DISTRIBUTION
WIND VELOCITY JULY - AUGUST
OMAHA, NEBRASKA

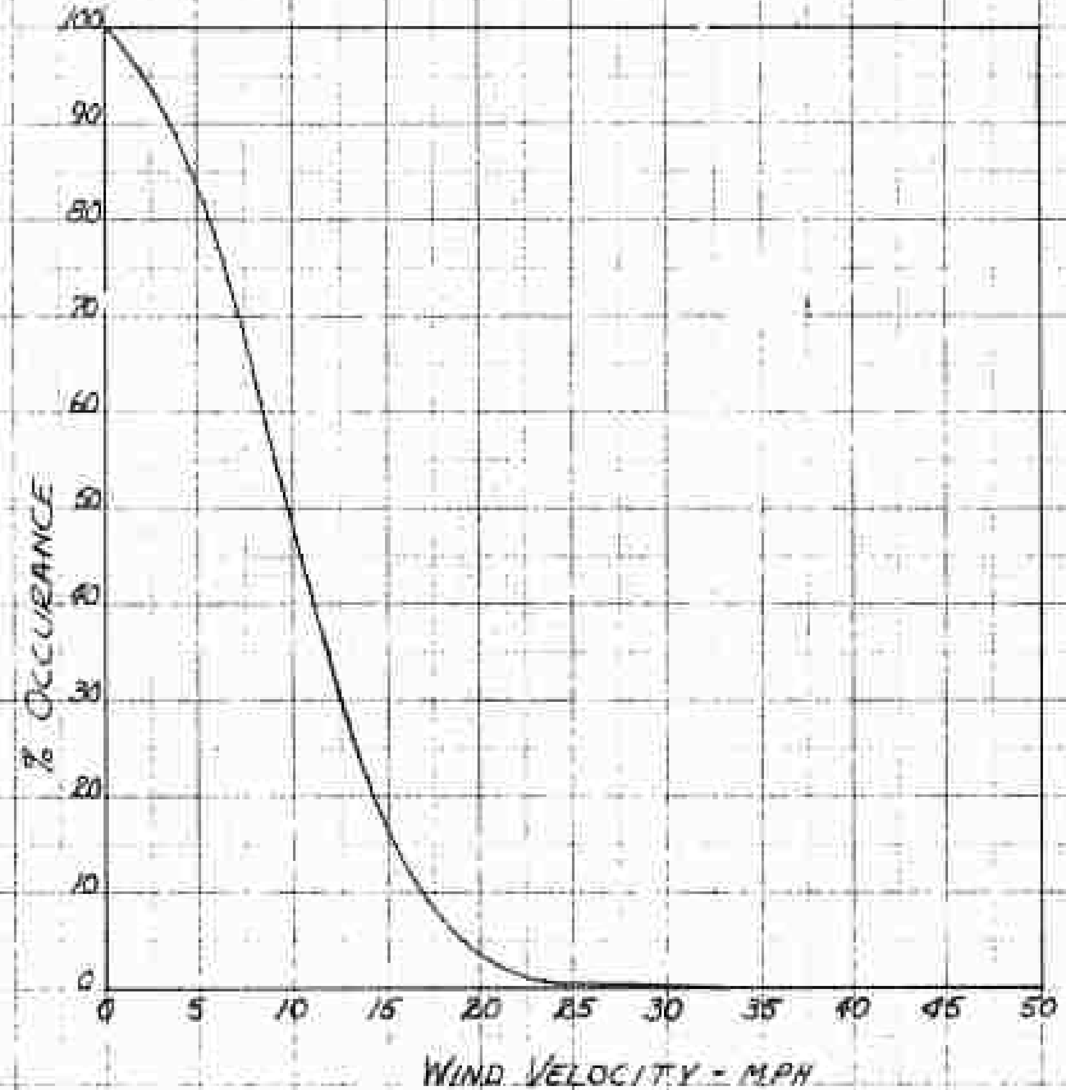

Fig. 1

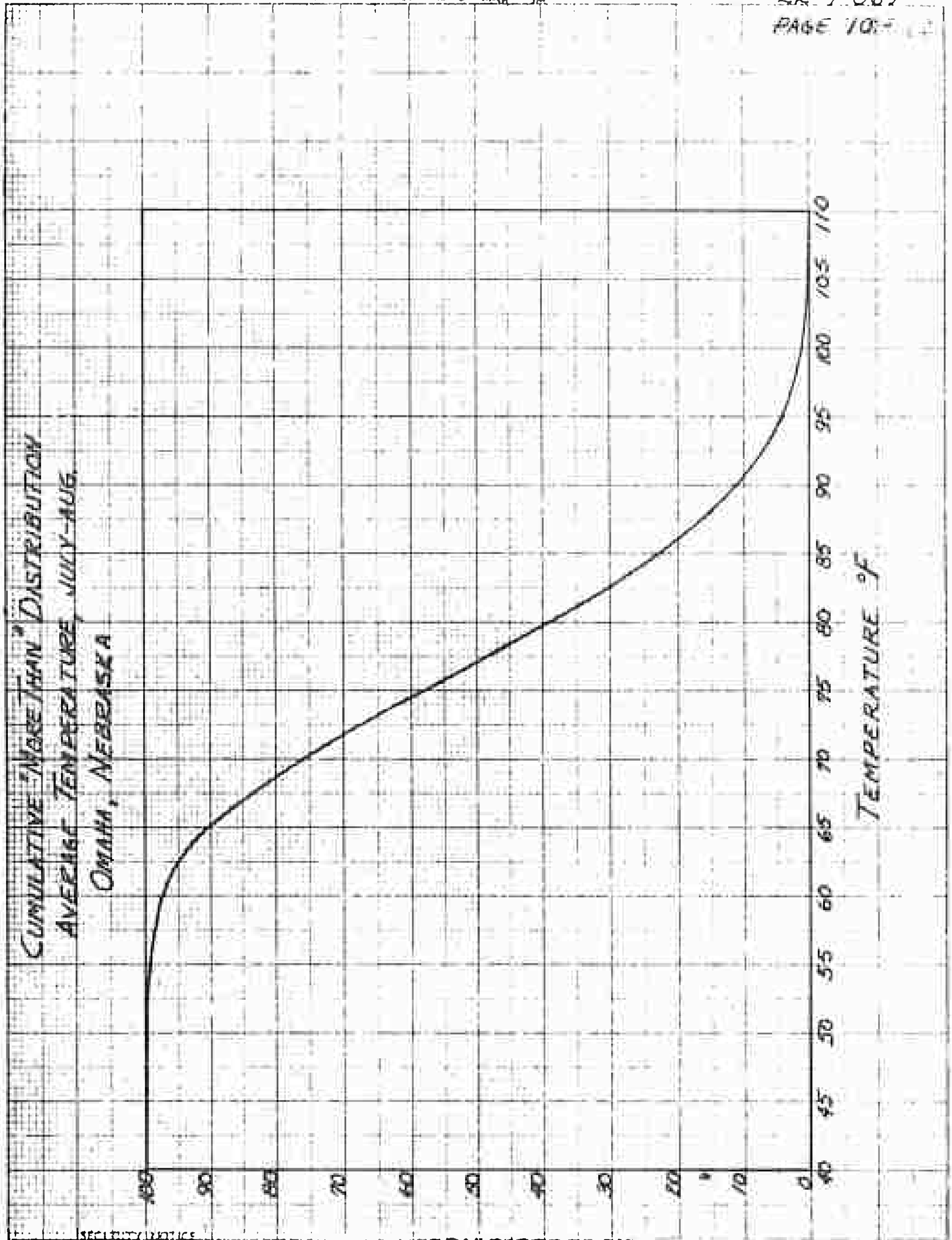
CUMULATIVE "MORE THAN" DISTRIBUTION
AVERAGE TEMPERATURE, JULY-AUG.
OMAHA, NEBRASKA
TEMPERATURE °F
% OCCURANCE
40 45 50 55 60 65 70 75 80 85 90 95 100 105 110
100 90 80 70 60 50 40 30 20 10 0

Fig. 2

CUMULATIVE "MORE THAN" DISTRIBUTION
RELATIVE HUMIDITY - JULY, AUG.
OMAHA, NEBRASKA

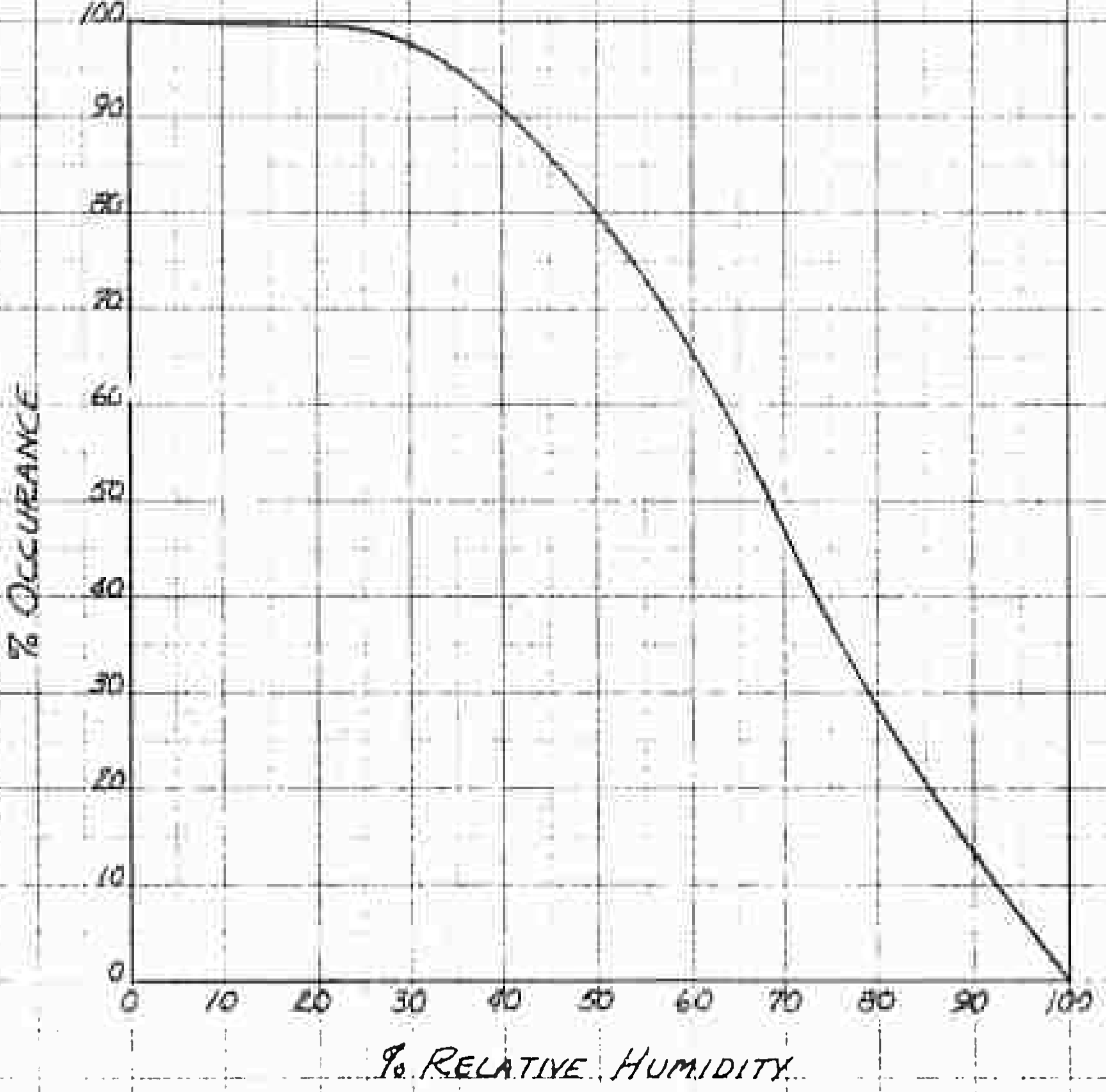

Fig. 3

CUMULATIVE "MORE THAN" DISTRIBUTION
AVERAGE HOURLY PRECIPITATION
JULY AND AUGUST
OMAHA, NEBRASKA

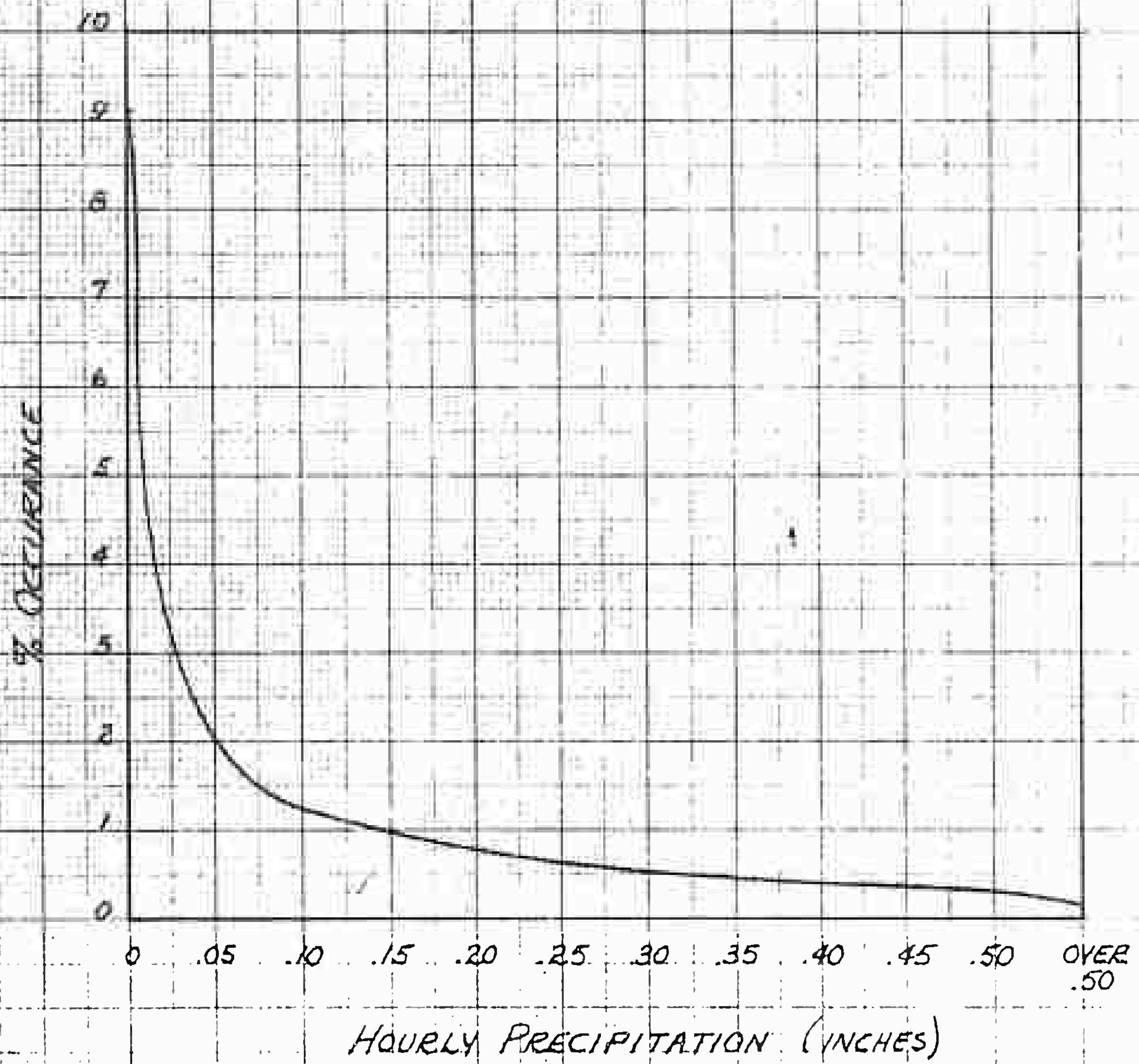

FIG. 4

CUMULATIVE "MORE THAN" DISTRIBUTION
WIND VELOCITY
JULY & AUGUST
OMAHA, NEBRASKA

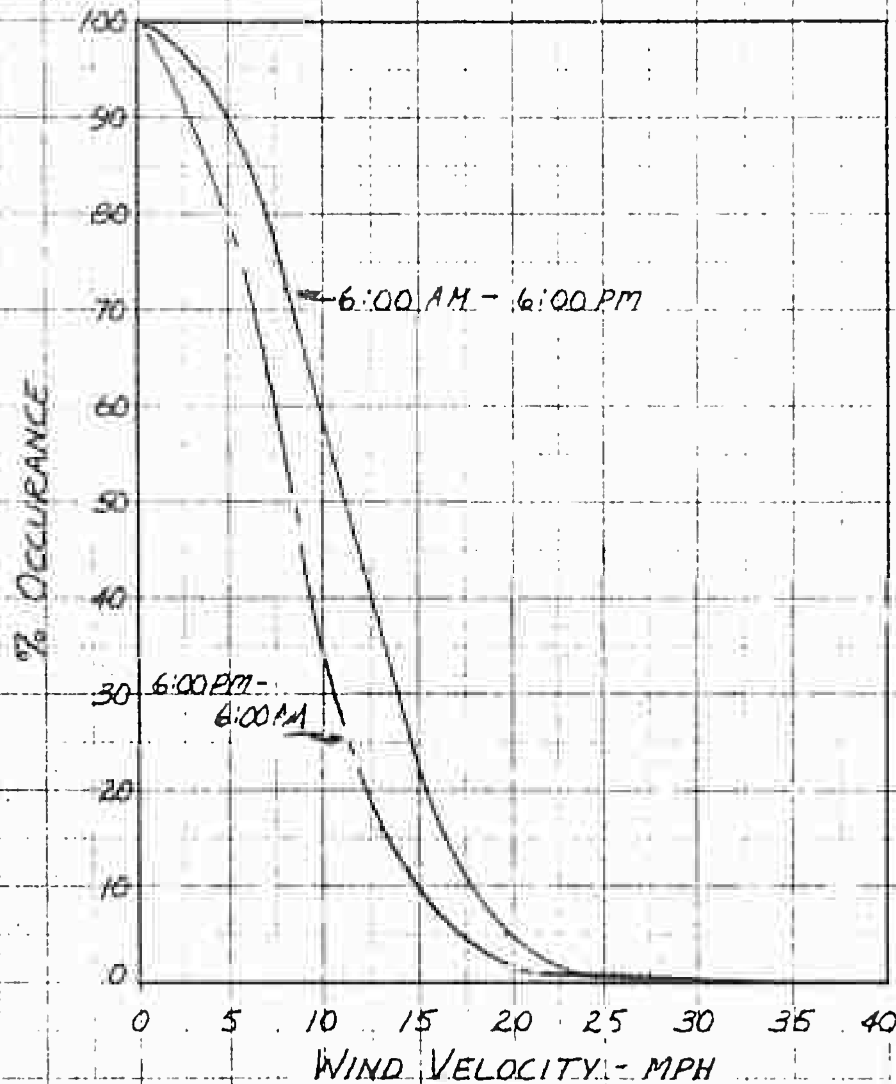

FIG 5

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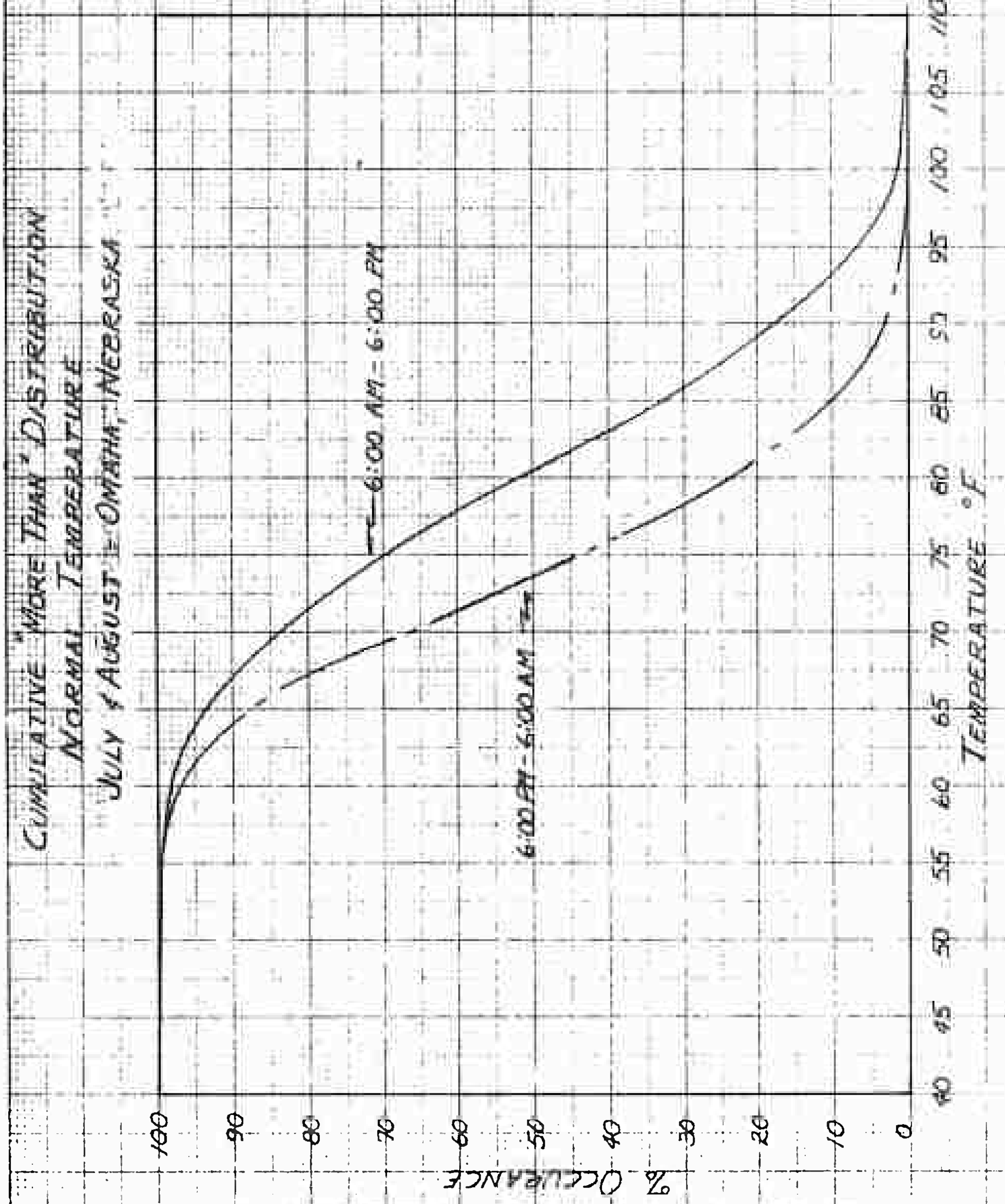

FIG 6

SECURITY NOTICE

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ZL 7-069

CUMULATIVE "MORE THAN" DISTRIBUTION
RELATIVE HUMIDITY
JULY & AUGUST
OMAHA, NEBRASKA

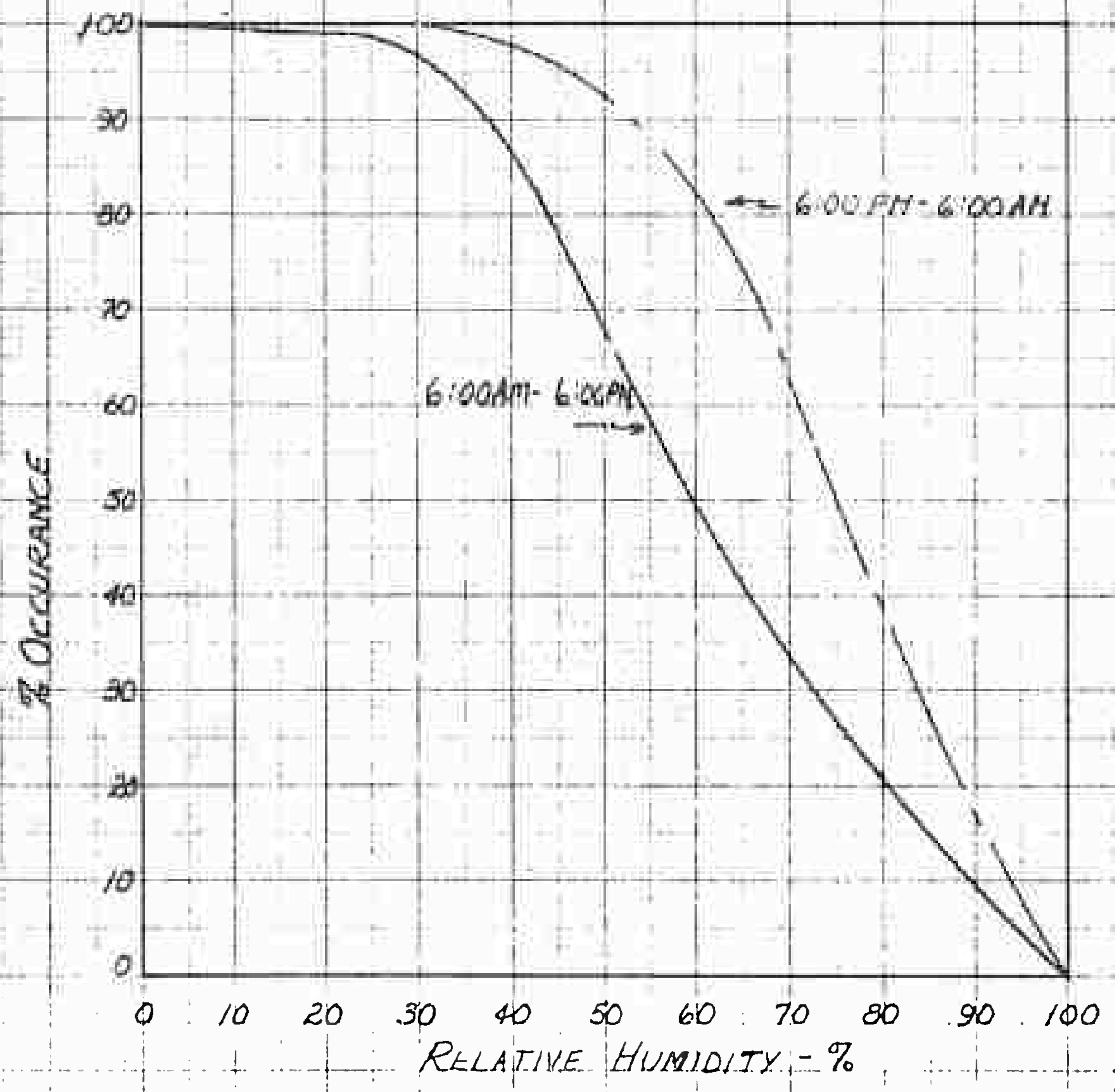

FIG 7

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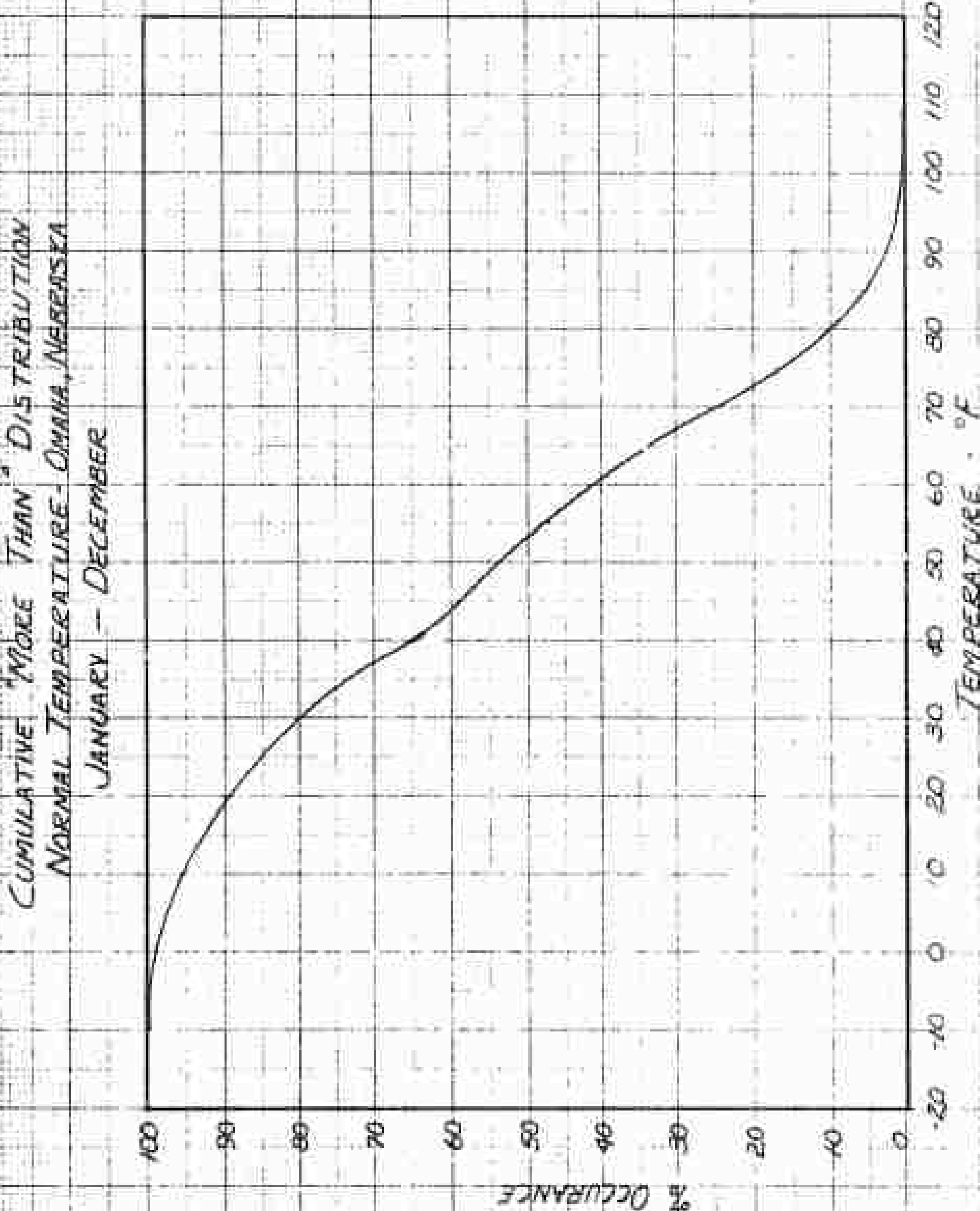

FIG 8

SECURITY NOTICE

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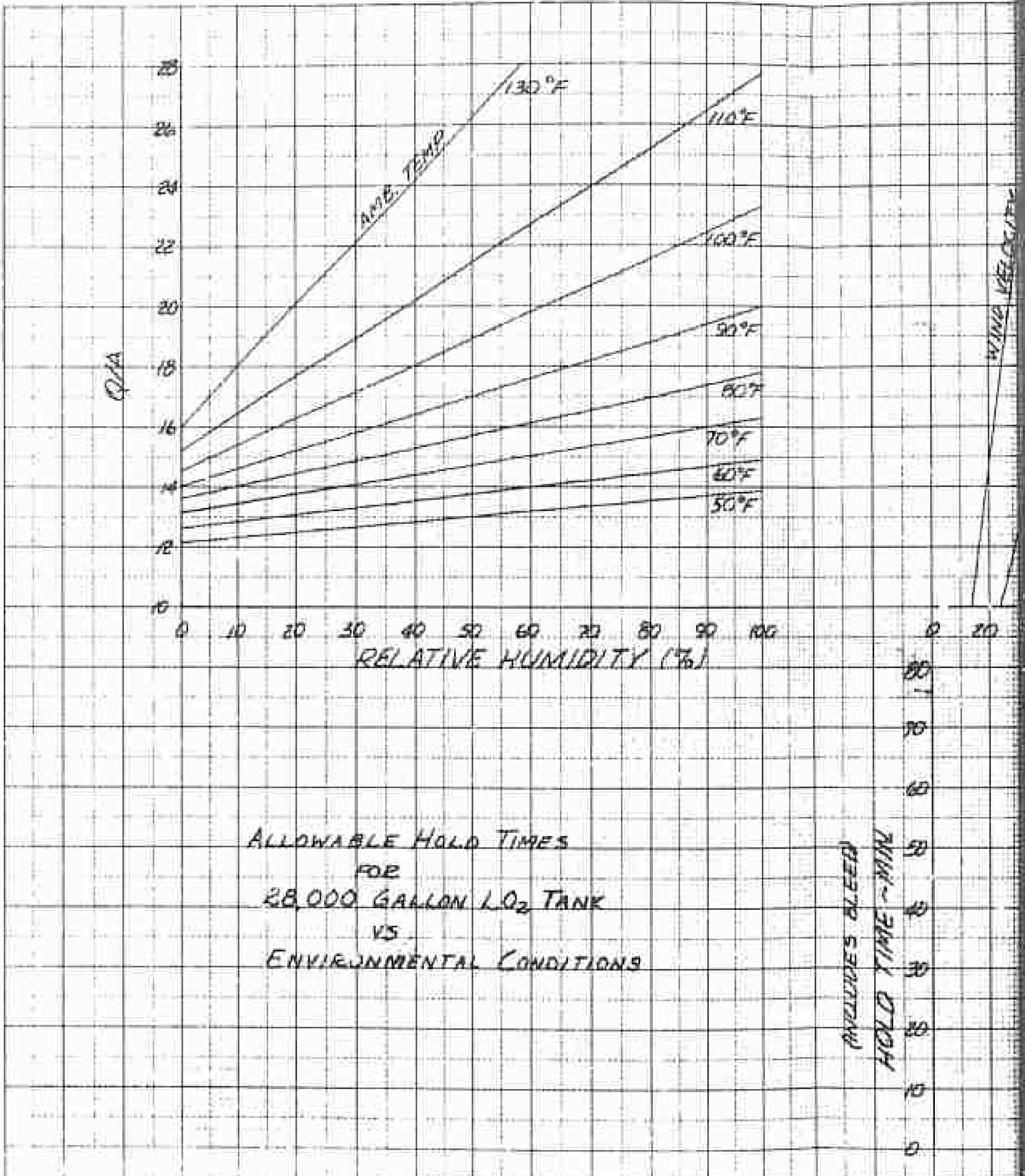
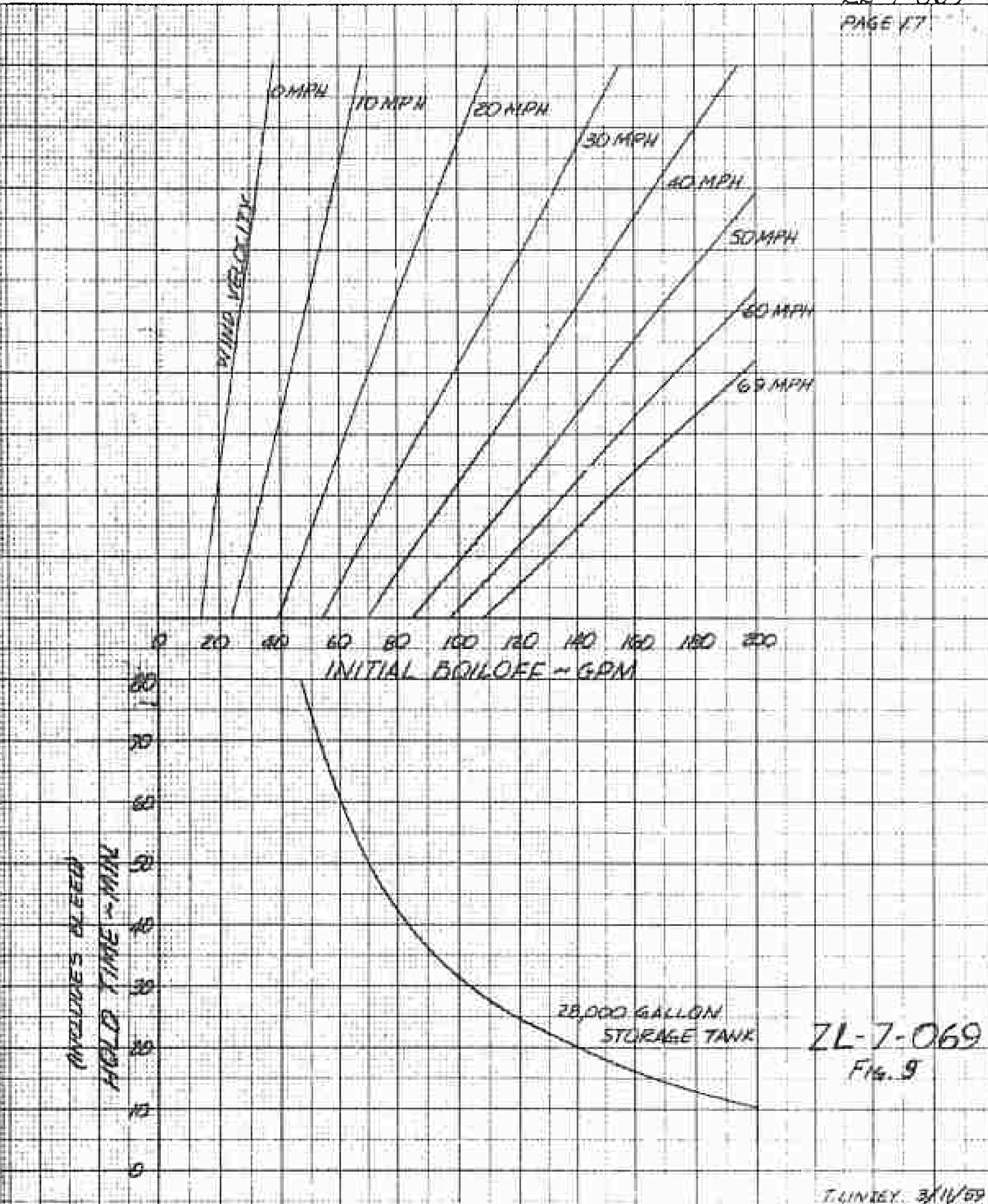

Q/A
28
26
24
22
20
18
16
14
12
10
AMB. TEMP
130°F
110°F
100°F
90°F
80°F
70°F
60°F
50°F
0
10
20
30
40
50
60
70
80
90
100
RELATIVE HUMIDITY (%)
WIND VELOCITY
0
20
HOLD TIME ~ MIN
(INCLUDES BLEED)
80
70
60
50
40
30
20
10
0
ALLOWABLE HOLD TIMES
FOR
28,000 GALLON LO_2 TANK
VS
ENVIRONMENTAL CONDITIONS

A



ZL-7-069
Fig. 9

T. LINZEY 3/11/69

B

PROBABILITY OF SYSTEM FUNCTIONAL FAILURE
DUE TO ADVERSE ENVIRONMENTAL CONDITIONS
OMAHA, NEBRASKA

MODEL DATE

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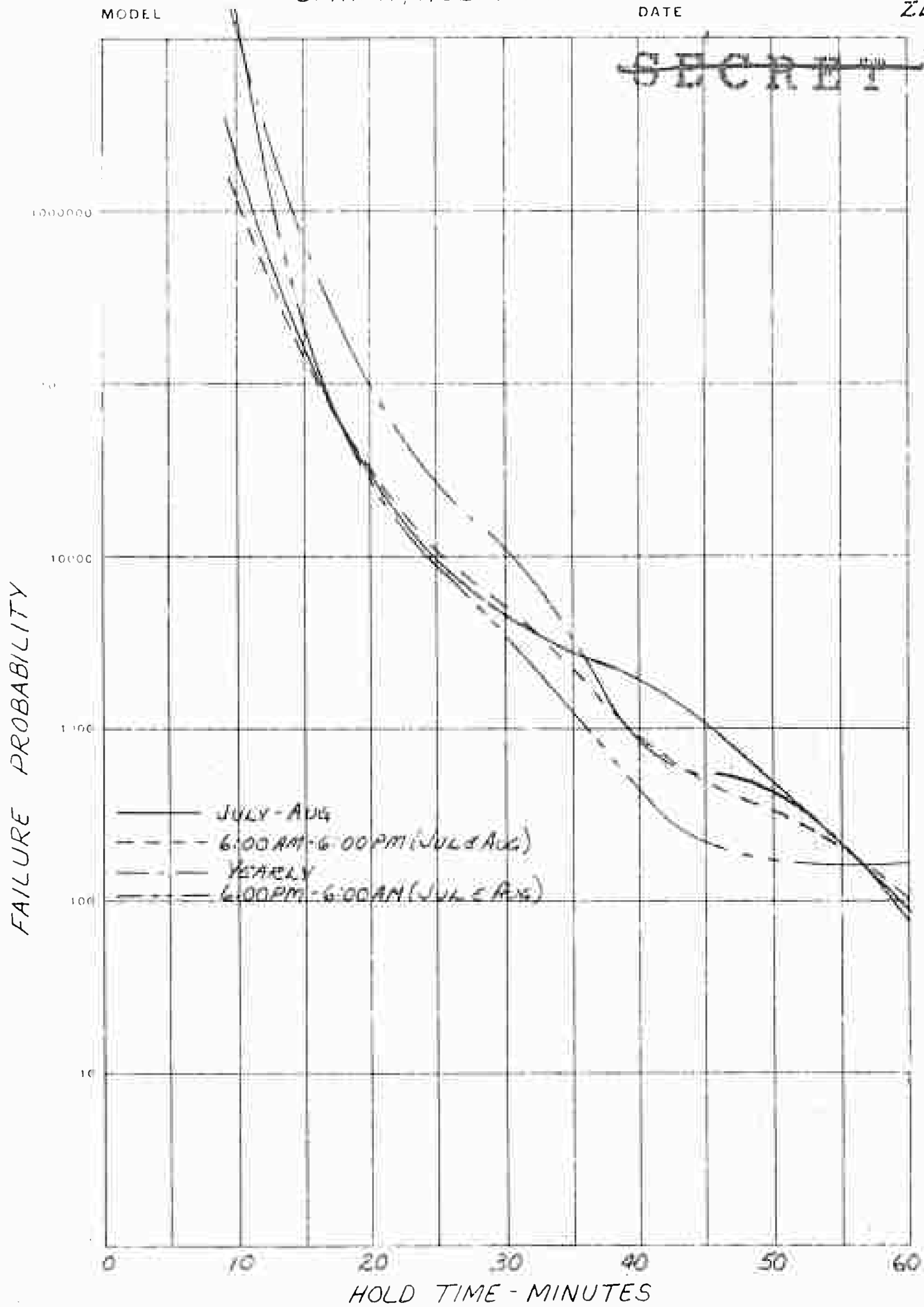

FIG 10

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